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Sequencing and Prior Information in Linear Programed Instruction

HERBERT R. MILLER

During the past eight or ten years, several principles have served as guidelines for the authors of linear instructional programs. The fact that research on these principles has offered no definitive patterns of support does not appear to have had any damaging effect on their general acceptance.

Logical sequencing of content in linear instructional programs is the principle under examination in this study. Skinner's (1953, p. 169) definition of programing as the "construction of carefully arranged sequences of contingencies leading to the terminal performances which are the object of education" is a historical antecedent of this principle and, indeed, the principle is still listed commonly among the characteristics of programed instruction.

Unfortunately, research comparing logically ordered programed sequences with nonlogical, or randomized sequences has been unable to lend much support to this principle. Studies by Gavurin and Donahue (1961), Roe, Case, and Roe (1962), Levin and Baker (1963), Hamilton (1964), Payne, Krathwohl, and Gordon (1967), and Miller (1965) were unable to demonstrate superiority in achievement for those subjects using logi-

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cally sequenced programs. Such superiority was demonstrated only in a study reported by Roe (1962). Considerable valid criticism has been directed against these studies by Holland (1965) and others. Areas of criticism included inappropriate combinations of program subject matter and learners, poor measures, poor programs, length of program, and the nature of the random or nonlogical sequences. Indeed, these criticisms have led some to dismiss the former six studies in favor of the one reported by Roe (1962), even though the Roe study was not above criticism.

Subsequent studies, which have taken into account these criticisms, have produced similar results, indicating that the tendency to dismiss earlier results as artifacts of bad design may have been premature. A study reported by Niedermeyer, Brown, and Sulzen (1968) found no significant differences in achievement between three sequence versions (logical, random, and reverse order). Wodtke, Brown, Sands, and Fredericks (1968) reported a study in which no significant difference in achievement was found after use of logical and nonlogical versions of a mathematics program which was presumed to have an important logical structure. Some evidence, however, was found to indicate a relative advantage of logical sequence for lower ability learners.

STATEMENT OF THE PROBLEM

Consideration of the problem of logical versus nonlogical sequencing in programed instructional materials suggests the following questions:

1. What effect does sequencing have on the effectiveness of a programed unit as measured by criterion and retention tests?
2. What effect does sequencing have on the efficiency of a programed unit as measured by time on the program, and number of errors on the program?
3. Will prior information in the form of an outline specifying the topics to be covered in the program be helpful to students (especially those using nonlogical sequences)?
4. Will the experimental variables have an effect on the mood or feelings of the students?
5. How will the students' level of subject matter achievement be related to sequencing and prior information variables?

The study reported in this paper was designed to suggest answers to these questions and to take account of as many of the criticisms of earlier studies as possible.

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EXPERIMENTAL DESIGN

A 2 x 4 fully crossed factorial design was used for each of two substudies. Eight programs on matrix arithmetic, representing all combinations of four methods of sequencing and two levels of prior information, were presented to two groups of experimental subjects.

Prior Information Variable

Half of the subjects in each substudy received as the first page of their programs an outline specifying the definitions and operations to be covered in the program. The other half of the subjects in each substudy did not receive the outline.

Sequencing Variable

Four different programed sequences were used, including the original logical version and three nonlogical versions constructed to present various combinations of disruption of logical sequence at two levels of content ordering. The sequencing treatments are illustrated in Figure 1.

FIGURE 1
Illustrative Example and Summary of Sequencing Treatments

Treatment			
Logical	*Nonlogical I*	*Nonlogical II*	*Nonlogical III*
A	B	B	R
B	L	A	S
C	N	C	T
D	R	D	U
K	A	L	A
L	U	N	B
M	M	M	C
N	T	K	D
R	C	R	K
S	K	U	L
T	D	T	M
U	S	S	N
Macro-order and micro-order preserved.	Macro-order and micro-order disrupted.	Macro-order preserved, micro-order disrupted.	Macro-order disrupted, micro-order preserved.

By designating the order of presentation of the sections of the program as macro-order, and the order of development within the sections as micro-order, the four sequencing treatments can be summarized quite briefly. The sequence used in *Logical* preserved both orders. The sequences in *Nonlogical I* disrupted both orders. Those used in *Nonlogical II* preserved macro-order but disrupted micro-order. The sequence used in *Nonlogical III* disrupted macro-order but preserved micro-order.

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The following is a more complete description of the various sequences used.

1. Logical. This was the standard version of the program, which covered matrix arithmetic in three sections: definitions; addition of matrices and multiplication by a scalar; and multiplication of two matrices. The logic of the program was that imposed by the interactions of the author, subject matter, objectives, and learners used in preliminary field trials. Therefore, both macro-order and micro-order were preserved.

2. Nonlogical I. This sequence was prepared by randomizing over the entire length of the original sequence, thus disrupting both macro- and micro-orders. Eight lists of random two-digit numbers from one to 96 were prepared as a basis for establishing the nonlogical sequences to be used in this treatment. The three nonlogical sequences having the largest numbers of short runs of content-related frames were then selected for use. It was felt that the absence of long runs of content-related frames, which can occur by chance in any randomly determined sequence, would tend to insure maximum disruptiveness of the original logic. The three sequences were used in order to minimize the probability that a single nonlogical sequence might actually be "logical" to some of the learners. Each of the sequences used in this treatment had zero rank order correlations with the logical version.

3. Nonlogical II. Each of the three learning sequences used in this treatment was derived from one of those used in Nonlogical I by extracting from a Nonlogical I sequence the frames belonging to each of the three sections of the original program. The frames from each section were grouped together (in their Nonlogical I order) and the sections were presented in their original 1-2-3 sequence, thus preserving only macro-order.

4. Nonlogical III. The learning sequence used in this treatment was prepared by presenting the three sections of the original program in the order 3-1-2. Therefore, multiplication of matrices came before any of the preliminary material, thus disrupting only macro-order.

EXPERIMENTAL SUBJECTS

A group of 119 eighth-grade students were used as subjects in Substudy I. In Substudy II, a group of 111 twelfth graders were used as experimental subjects. Although the twelfth graders had studied determinants, none of the experimental subjects had studied matrix arithmetic in school, and all met the criterion of entering behaviors as specified by the program author.

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EXPERIMENTAL MATERIALS

Programed Unit

A 96-frame linear programed instructional unit on matrix arithmetic was selected for use in this study (Ablon, 1962). The style of the program was brisk and clear, without the apparent redundancy associated with many linear programs. The program was developed in a workshop at the University of Rochester according to methods suggested by Lysaught and Williams (1963), and is considered to be among the best of the many programs written at these workshops over the past several years. It was field tested successfully by its author, and has been used in a study of predicted and actual success of instructional programmers (Lysaught & Pierleoni, 1966).

Criterion Measure

A 46-item objective criterion measure, requiring constructed, matching, *yes-no*, and multiple choice responses, was developed for use in this study. The reliability of the measure was estimated to be 0.90 by the Kuder-Richardson Formula Number 21.

Measure of Mood

Because other investigators of sequencing had indicated that nonlogical sequences appear to challenge some learners more than logical sequences (e.g. Roe, Case, & Roe, 1962, p. 104), an effort was made to assess change in mood as a result of the experimental treatments. For this purpose, a shortened version of the Mood Adjective Check List (MACL) (Nowlis & Green, 1965, p. 111) was used. The list consisted of three adjectives on each of nine factors: aggression, anxiety, surgency, concentration, fatigue, social affection, sadness, egotism, and skepticism. By asking the subjects to relate each adjective to their feelings before and during the experimental treatment, changes in mood could be detected.

DATA COLLECTION AND ANALYSIS

Students in each of the substudies were randomly assigned to one of the eight treatment combinations. Because it was necessary to work within the framework of the regular mathematics class period, Substudy I (eighth graders) was carried out on successive days Monday through Friday of one week, and Substudy II (twelfth graders) was carried out in a different school on successive days from Monday through Thursday of another week. At no time were experimental materials used outside the classroom.

Subjects were not pretested on matrix arithmetic because pretesting would have damaged the prior information variable, and it was determined that the experimental subjects had not studied matrices as a part of their regular curriculum. Immediately after instructions were completed on the first day, the first MACL was administered to the subjects, who then commenced

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work on the program. The second MACL was administered at the end of the second day in order to assure that all subjects would have spent approximately the same amount of time under the experimental treatment. As soon as each subject finished working on the program, he took the criterion measure. Approximately one month later, the same criterion measure was administered as a measure of retention. At this point, the purpose of the study was explained to the subjects.

Only four of the 119 subjects in Substudy I were lost because of absence, and only two of 111 in Substudy II.

Two scores were obtained from the criterion and retention measures: the definition-addition score, derived from all items covering the definition and addition of matrices (maximum of 31 points), and the multiplication score, derived from those items covering the multiplication of two matrices (maximum of 26 points). In addition, data were also collected on time spent on the program and number of errors on the program.

These data were analyzed with 2 x 4 analyses of variance, with two planned comparisons along the sequencing dimension (Hays, 1963, Ch. 14). Comparison 1 was designed to compare the mean value for the Logical treatment with an average of the mean values for all Nonlogical treatments. Comparison 2 was designed to compare the effect of disrupting micro-order with that of disrupting macro-order by comparing means for Nonlogical II and Nonlogical III. In order to preserve the orthogonality of the planned comparisons, it was necessary to randomly eliminate subjects from certain cells before the analyses of variance were performed. Any additional comparisons suggested by the remainder of the sequencing sum of squares were to be performed with a post hoc method, such as the Scheffé test (Hays, 1963, Ch. 14).

Because MACL is a measure of mood *change*, difference scores were obtained by subtracting scores on the first administration of the measure from corresponding scores on the second. It was felt that a nonparametric (or distribution-free) test would be more appropriate inasmuch as these data were considered to be ordinal. Therefore, a distribution-free test of analysis of variance hypotheses suggested by Wilson (1956) was used to analyze the data on each of the nine factors of the MACL.

The level of significance for rejection of all hypotheses was set at .05.

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RESULTS: SUBSTUDY I *Eighth Graders*

Prior information (row) means, sequencing (column) means, and the average of all Nonlogical treatment means (used in Comparison 1) for Substudy I are presented in Table 1.

TABLE 1

Means for Prior Information (Row), Sequencing (Column), and All Nonlogical (Comparison 1) Treatments on All Dependent Variables for Substudy I

Dependent Variables	*Prior Information Means*		*Sequencing Means*				
	Prior Information	*No Prior Information*	*Logical*	*Nonlogical I*	*Nonlogical II*	*Nonlogical III*	*All Nonlogical*
Criterion Measure							
Definition-Addition Score (max. 31)	26.75	26.45	26.30	26.74	27.15	26.26	26.71
Multiplication Score (max. 26)	13.05	12.75	14.33	12.44	14.07_a	10.78_a	12.43
Retention Measure							
Definition-Addition Score (max. 31)	25.67	25.04	25.23	25.69	26.27	24.27	25.41
Multiplication Score (max. 26)	11.26	12.14	12.19	11.46	12.54	10.54	11.51
Time on Program (minutes)	90.51	85.63	88.36	91.38	90.70_b	82.31_b	88.13
Errors on Program	19.32	19.08	15.00_d	23.96	22.33_c	15.70_c	20.66_d

a. Comparison 2; $F = 4.52$, $df = 1{,}100$
b. Comparison 2; $F = 5.99$, $df = 1{,}96$
c. Comparison 2; $F = 4.18$, $df = 1{,}99$
d. Comparison 1; $F = 6.59$, $df = 1{,}99$

Sequencing

With respect to the sequencing variable, no significant differences were found in the definition-addition portion of either the criterion or retention measures. The general level of performance on both was satisfactory, although it can be seen that the mean scores for the retention measure were three to five percent lower than those on the criterion measure.

The mean scores for all Nonlogical treatments were lower than those for the Logical treatment on the multiplication portion of both the criterion and retention measures, but these differences were not significant.

On the multiplication portion of both measures, it should be noted that subjects in the two treatments in which macro-order

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was preserved (Logical and Nonlogical II) performed at a higher level than those in treatments in which macro-order was disrupted. On the criterion measure, subjects using the program in which macro-order had been preserved, but micro-order disrupted (Nonlogical II) performed at a significantly higher level than those using the program in which macro-order had been disrupted, but micro-order preserved (Nonlogical III) (see Table 1). This difference was also found on the retention measure, but was not significant.

Subjects in Nonlogical III made significantly fewer errors and took significantly less time on the program than those in Nonlogical II (see Table 1). Also, subjects in the Logical treatment made significantly fewer errors than those in all Nonlogical treatments (see Table 1). In general, it can be seen from Table 1 that subjects using programs in which micro-order was disrupted spent more time and made more errors on the program than those using programs in which micro-order was preserved. No significant differences ascribable to sequencing were found on any of the factors of the MACL.

Prior Information

With respect to the prior information variable, the only significant difference found was on the sadness factor of the MACL. Subjects receiving the prior information became more sad than those not receiving this information ($\chi^2 = 6.93$, $df = 1$). On the criterion and retention measures, subjects who received the prior information performed at a level only slightly higher than those not receiving the information.

Interaction

Finally, with respect to the interaction of the sequencing and prior information variables, the only significant difference found was on the anxiety factor of the MACL ($\chi^2 = 8.48$, $df = 3$).

RESULTS: SUBSTUDY II

Twelfth Graders

Mean scores for this substudy are presented in Table 2.

Sequencing

With respect to the sequencing variable, subjects using the program which disrupted both macro- and micro-order (Nonlogical I) performed at a significantly higher level on the definition-addition portion of the criterion measure than those using the program in which only macro-order was disrupted (Nonlogical III) (see Table 2). On the same portion of the retention measure, those using the program in which macro-order was preserved, but micro-order disrupted (Nonlogical II) performed at a significantly higher level than those using a program in which only macro-order was disrupted (Nonlogical III) (see

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TABLE 2

Means for Prior Information (Row), Sequencing (Column), and All Nonlogical (Comparison 1) Treatments on All Dependent Variables for Substudy II

	Prior Information Means		*Sequencing Means*				
Dependent Variables	*Prior Information*	*No Prior Information*	*Logical*	*Nonlogical I*	*Nonlogical II*	*Nonlogical III*	*All Nonlogical*
Criterion Measure							
Definition-Addition Score (max. 31)	30.13	30.00	30.11	30.63_a	29.93	29.59_a	30.05
Multiplication Score (max. 26)	19.93	20.30	21.93	19.93	21.07_b	17.52_b	19.50
Retention Measure							
Definition-Addition Score (max. 31)	28.95	28.86	29.00	29.08	29.84_c	27.72_c	28.88
Multiplication Score (max. 26)	16.53	17.31	18.28	16.68	17.49	15.28	16.48
Time on Program (minutes)	75.06	79.27	71.60_d	81.46	81.00	74.31	78.92_d
Errors on Program	10.22	10.93	6.53_{efg}	13.74_g	12.19_g	9.74_{fg}	11.89_e

a. post hoc comparison; Scheffé test with upper limit 1.899 and lower limit 0.181
b. Comparison 2; $F = 4.92$, df = 1,100
c. Comparison 2; $F = 6.58$, df = 1,92
d. Comparison 1; $F = 5.38$, df = 1,95
e. Comparison 1; $F = 26.26$, df = 1,100
f. post hoc comparison; Scheffé test with upper limit 5.605 and lower limit 0.615
g. post hoc comparison of Logical and Nonlogical III with Nonlogical I and Nonlogical II; Scheffé test with upper limit —3.014 and lower limit —6.546

Table 2). Nonlogical III registered the largest decrease from criterion to retention measure, but all scores were at a high level.

On the multiplication portion of both the criterion and retention measures, subjects in the Logical treatment performed at a higher level than those in all Nonlogical treatments; these differences, however, were not significant. On the criterion measure, subjects in Nonlogical II performed significantly better than those in Nonlogical III (see Table 2). This difference persisted in the retention measure, but was not significant. For the multiplication portion of both measures, subjects using programs in which macro-order was preserved (Logical and Nonlogical II) performed at a higher level than those using pro-

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grams in which macro-order was disrupted (Nonlogical I and Nonlogical III). Scores on this portion of the retention measure were about 15 percent lower than those on the criterion measure.

Subjects in the Logical treatment made significantly fewer errors and took significantly less time on the program than those in all Nonlogical treatments (see Table 2). Also, subjects in Logical made significantly fewer errors than those in Nonlogical III (see Table 2). Those subjects using programs in which micro-order was preserved (Logical and Nonlogical III) took less time and made fewer errors than those using programs in which micro-order was disrupted (Nonlogical I and Nonlogical II); this difference was significant only for the error data (see Table 2). No significant differences ascribable to sequencing were found on any factors of the MACL.

Prior Information

With respect to the prior information variable, the only significant difference found was on the skepticism factor of the MACL. Subjects who received the prior information showed a significant decrease in skepticism compared to those who did not receive the information ($\chi^2 = 4.52$, $df = 1$). On the definition-addition portion of both the criterion and retention measures, subjects receiving the prior information performed at a slightly higher level than those not receiving the information; on the multiplication portion of both measures, the former subjects performed at a slightly lower level than the latter.

Interaction

Finally, with respect to the interaction of the prior information and sequencing variables, no significant differences were found on any of the dependent variables.

DISCUSSION

In both substudies, the treatment groups that registered the better performances on the multiplication portion of both the criterion and retention measures were those in which macro-order was preserved (Logical and Nonlogical II). It would appear to be beneficial, therefore, to have some knowledge of what a matrix is before one attempts to learn how to multiply two of them. This would seem to be consistent with Gagné's (1962) notion of the existence of hierarchies of learning tasks. In order to achieve a specific overall objective, there may be subordinate tasks which must be accomplished in a particular order. In both substudies, the significant superiority of Nonlogical II (which preserved macro-order but disrupted micro-order) over Nonlogical III (which disrupted macro-order while preserving

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micro-order) on the multiplication portion of the criterion measure lends additional support to Gagné's ideas, and further, supports the suggestion by Williams (1966) that the attainment of individual tasks within a hierarchy can be accomplished in a number of ways, including nonlogical programed sequences. These results suggest that there exists a point beyond which fastidious attention to logical sequencing will not return dividends in program effectiveness proportionate to the effort expended.

Also, subjects using the nonlogical sequences performed as well as those using the original logical sequence with respect to the definition and addition of matrices, tending to confirm suggestions by other investigators in this area that students can rearrange information effectively. A tentative explanation for this behavior can be extracted from the work of Bousefield and others (see for example, Bousefield, 1953) on a phenomenon called *clustering* as it relates to Hebb's (1949, pp. 95-98) account of superordinate and subordinate perceptions.

CONCLUSIONS

The following paragraphs suggest answers to the questions posed earlier in this paper; the numbers of the paragraphs correspond to those of the questions.

Sequencing and Effectiveness

1. With respect to the definition and addition of matrices, the nonlogical sequences worked as effectively as the logical sequences. Students apparently were able to overcome any difficulties caused by the disruption of micro-order through some means of mental reorganization of the information. Such a means was suggested, based on the theoretical work of Hebb and Bousefield. With respect to the multiplication of matrices, disruption of micro-order again failed to interfere with the satisfactory acquisition of the information. However, disruption of macro-order did interfere with satisfactory acquisition.

The same trends observed in the criterion measure persisted in the retention measure. No sequencing treatment appeared to affect retention in any unusual way. The general conclusion reached in this study is much the same as the suggestion by Hamilton (1964)—sequence of frames does not make a difference as long as the order of concepts is preserved. In particular, if certain tasks are subordinate to some higher level task, these tasks must be accomplished in the proper sequence. As long as this condition is met, the actual sequence of frames may not be of importance.

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Sequencing and Efficiency

2. Disruption of micro-order was more costly in terms of time spent on the program, and number of errors on the program. If both achievement and efficiency in terms of time and errors are important, the original logical sequence must be judged the best in this study. If time and errors are not of importance, both the original program and the nonlogical sequence in which macro-order was preserved but micro-order disrupted appeared to produce comparable achievement.

Prior Information

3. The availability of prior information apparently was of no help to the subjects. Mager's (1962) suggestion that one might need to do little more than give students a list of objectives was not supported in this study.

Mood Change

4. Although there would seem to be little doubt that exposure to a learning sequence would have some effect on a student's mood or feelings, practically no significant changes in mood were detected in this study. Aside from a significant decrease in skepticism for subjects who received prior information in one of the substudies, there were no other effects of interest attributable to the experimental variables.

Comparison of the Two Substudies

5. The results of both substudies were strikingly similar. The overall lower level of performance of the junior high school students was attributed to their lower level of mathematical attainment. Also, it was concluded that the original program could have been more effective in teaching multiplication of matrices to the junior high school students.

IMPLICATIONS

The results of this study would not seem to justify the construction of linear programed sequences in an intentionally nonlogical way; logical sequence still appears to be the best in terms of overall effectiveness and efficiency. On the other hand, these results do question the necessity for laboring over their construction, using rigorous methods of content sequencing such as mathematics. It would seem to be a profitable expenditure of time to employ such methods only to the point of assuring that all learning tasks subordinate to the principal task at hand are accomplished in the proper sequence. As indicated earlier, it would seem to be of value to identify the levels at which sequencing is important, so that the effort expended in constructing a learning program can be directed towards doing the most good.

Indeed, one could go on to question the value of a strictly linear program. Such programs make no provision for correcting learner errors, or accommodating individual differences. Be-

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cause it seems reasonable to assume that individual learners will bring more or less unique backgrounds and requirements to a given learning situation, the work to be done in the near future with sophisticated branching techniques and computer-assisted instruction should be of considerable interest to those concerned with the most effective sequencing of instructional content.

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